APPENDIX D
EXCERPT FROM 1997 KAEMPFER & ASSOCIATES, INC. REPORT

CHAPTER 3

STUDY AREA CHARACTERISTICS

In planning for the long-range development of a public water supply system, proper consideration of physical and economic factors influencing growth in the service area must be made. Physical characteristics of importance to the study include topography, geology, and climate; while economic characteristics of interest include commerce, industry, agriculture, transportation, and utilities. These factors have a bearing on land use patterns and population growth and consequently affect the location, design, and operation of water supply facilities.

This chapter summarizes information related to the physical and economic characteristics pertinent to this study. Detailed information can be obtained from the published reports referenced in the text.

STUDY AREA

The City of Fond du Lac, as shown in Figure 3-1, is located at the south end of Lake Winnebago in the east-central portion of Wisconsin, approximately 36 miles west of Lake Michigan. It is approximately 60 miles northwest of Milwaukee, 70 miles northeast of Madison, and 55 miles southwest of Green Bay. The City of Fond du Lac is located in the center of Fond du Lac County and is the county seat.

The extent of the area that will be considered for detailed study is shown in Figure 3-2. The study area includes the City of Fond du Lac, the Villages of North Fond du Lac and Oakfield, the Town of Fond du Lac, and portions of the Towns of Taycheedah, Empire, Eden, Byron, Oakfield, Lamartine, Eldorado, and Friendship. The study area is about 12 miles from east to west, 12 miles from north to south, and encompasses an area of about 144 square miles.

PHYSICAL ENVIRONMENT

Significant physical features which affect water supply planning include topography, geology, soils, climate, and hydrology. These features are discussed briefly in this chapter; and where pertinent to specific topics, additional information regarding physical characteristics will be presented in later chapters.

Topography

The topography of any area, including ground slope and natural drainage features, is the surface expression of its geologic and climatologic past. Topography has a direct bearing on land use, population distribution, and population density. With regard to water supply planning, topography dictates the location of reservoirs and determines the configuration of pressure zones necessary to maintain service pressure within acceptable limits.

Fig. 3-1 Vicinity Map

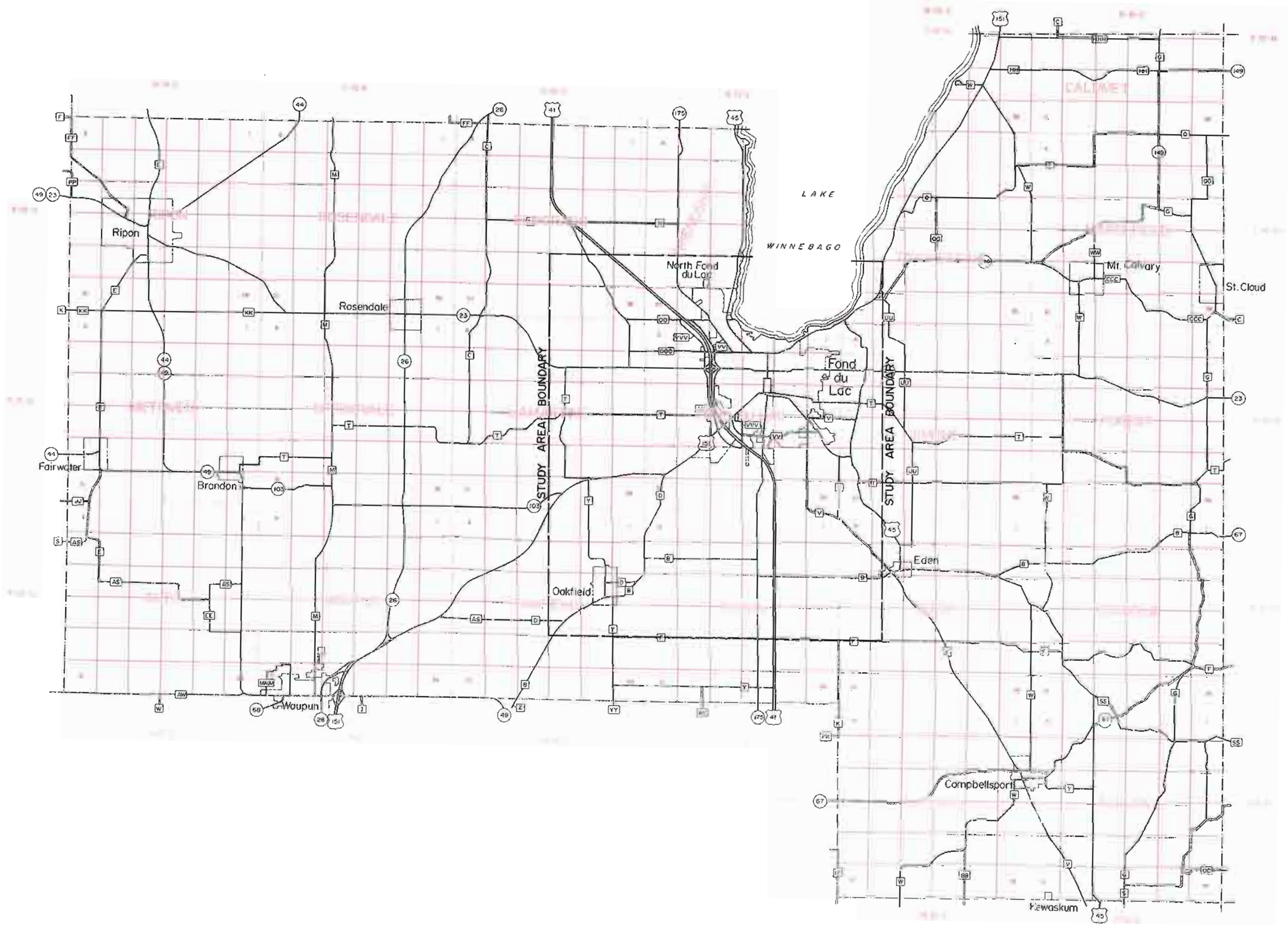


Fig. 3-2 Study Area

The topography of the study area, as shown in Figure 3-3, has a number of distinct features. In the northern portion of the study area a gently sloping plain extends from Lake Winnebago southward three to four miles where it meets a low ridge on the south and west, and the Niagara Escarpment on the east. The ridge rises 30 to 50 feet and forms a semi-circle around the southern end of Lake Winnebago. The Niagara Escarpment, the most significant topographic feature, rises steeply 150 to 250 feet along the eastern and southern edges of the study area. In the southeast portion of the study area the land consists of gently rolling hills. In the central portion of the study area, the east branch of the Fond du Lac River Valley widens to form a gently sloping plain three to four miles wide. The western portion of the study area rises to form a series of hills and ridges.

Elevations range from 747 feet in the northern portion of the study area along Lake Winnebago to over 1,160 feet in the southeastern portion of the study area at the top of the Niagara Escarpment. In the western portions of the study area elevations range to over 900 feet. Elevations within the presently developed area served by the Fond du Lac Water Utility range from 750 feet at Lake Winnebago to over 1,000 feet along the escarpment on the east side of the city. The majority of the present service area is between 750 and 850 feet.

Drainage in the study area is predominantly northerly to Lake Winnebago. A small portion of the study area in the southeast corner drains directly to Lake Michigan. The major drainage courses are the east branch of the Fond du Lac River which drains the central and southwest portions of the study area, and the west branch of the Fond du Lac River which drains the west and northwest portions of the study area. The eastern portions of the study area are drained by Taycheedah and De Neveu Creeks. The northern portions of the study area are drained by Mosher and Anderson Creeks and the southeastern portions of the study area are drained by tributaries of the Milwaukee River.

The entire study area is well drained. The only wetland areas are a portion of the Eldorado Marsh that is located in the northwest portion of the study area, and some small marshes located at the base of the escarpment in the southern portion of the study area.

Geology and Groundwater Hydrology

The regional geology in the vicinity of Fond du Lac has been described in several previous groundwater reports(1)(2) and can be interpreted from unpublished water well logs compiled by the Wisconsin Geological and Natural History Survey.(3) For the purposes of describing the occurrence of groundwater, local geologic formations can be divided into; unconsolidated sedimentary rocks, consolidated sedimentary bedrock, and crystalline basement rocks. The most important local groundwater sources, the bedrock units, are further subdivided into stratigraphic units.

The generalized geologic column for the Fond du Lac area is shown in Table 3-1. The youngest rock units are at the top of the table, with successively older rock units listed beneath the younger ones. This table also summarizes the lithology of major rock units and their water bearing properties. More detailed geologic charts of these units are available(4) in Appendix "B", but are not important for understanding the local influences of geology on Fond du Lac groundwater occurrence and availability.

LEGEND

—950— EXISTING GROUND SURFACE CONTOURS

Fig. 3-3
Topography

Unconsolidated Sedimentary Rocks. Surficial deposits consist of small amounts of alluvial material along existing streams. The clay, peat, silt, and sand is thin, limited in extent, and does not comprise a reliable source of groundwater for municipal use.

Most surficial deposits consist of glacial drift. Glacial drift is the term used to describe all sediments deposited by or from glacial ice or the water derived from the melting of glacial ice. Drift near Fond du Lac ranges in thickness from 0 to more than 100 feet. The drift is composed of stratified clays, sands, and gravel where the major agent of deposition was water. The drift is composed of rock fragments that are unsorted and non-layered where materials were deposited directly by ice. Previous studies and evaluation of water-well logs indicate that drift is not an adequate source of groundwater to high-yield wells near the City of Fond du Lac.(1)(2)

Consolidated Sedimentary Bedrock. The consolidated bedrock units underlying the Fond du Lac area are shown in Figure 3-4. The bedrock units were deposited during the Cambrian through Silurian periods of geologic time, as shown in Table 3-1. These units, formed between 600 and 400 million years ago(5), now dip gently to the east and southeast, with the youngest formations at the surface in the eastern part of Fond du Lac County. The generalized cross sections in Figures 3-5a, 3-5b, and 3-5c help clarify this stratigraphic relationship.

The youngest bedrock unit in the study area is the Niagara Series, which crops out at the Niagara Escarpment and underlies the area east of the escarpment. The Niagara Series is a medium gray to white dolomite with abundant variably distributed fractures. Dolomite is a combination of magnesium carbonate and calcium carbonate deposits. The Niagara Series is commonly referred to as the Niagara Dolomite. Groundwater in the Niagara dolomite occurs in openings along fractures and bedding planes, many of which have been enlarged by the solvent action of circulating groundwater.

The Neda Formation, encountered in some water wells in the country between the Niagaran dolomites and the underlying Maquoketa Shale, is a formation less than 20-feet thick that consists of shale and dolomite. It is not as important as an aquifer.

The Maquoketa formation, which is informally known as the Maquoketa Shale, is a soft, dolomitic shale, interstratified with thin beds of dolomite. The formation lies at the base of the Niagara Escarpment, and underlies the Niagaran dolomite east and south of the escarpment. The Maquoketa Shale has also been reported in several wells west of Fond du Lac; however, these outlying formations are not connected to the main portion of the formation. The Maquoketa Shale yields only relatively small amounts of water to wells. Wells that encounter the formation must be cased through the shale section because it sloughs into open holes.

The Sinnipee Group, comprising the Galena, Decorah, and Platteville formations, lies beneath the Maquoketa Shale. The Sinnipee Group forms the bedrock beneath the drift in the immediate vicinity of Fond du Lac. The rocks in the Sinnipee Group are dolomitic, average about 200 feet thick, and have a maximum thickness of 335 feet near Fond du Lac. The unit yields small to moderate amounts of groundwater to domestic and agricultural wells, primarily in the area where it is in direct contact with drift. Groundwater in the Sinnipee Group occurs in openings along fractures and bedding planes, many of which have been enlarged by groundwater circulation.

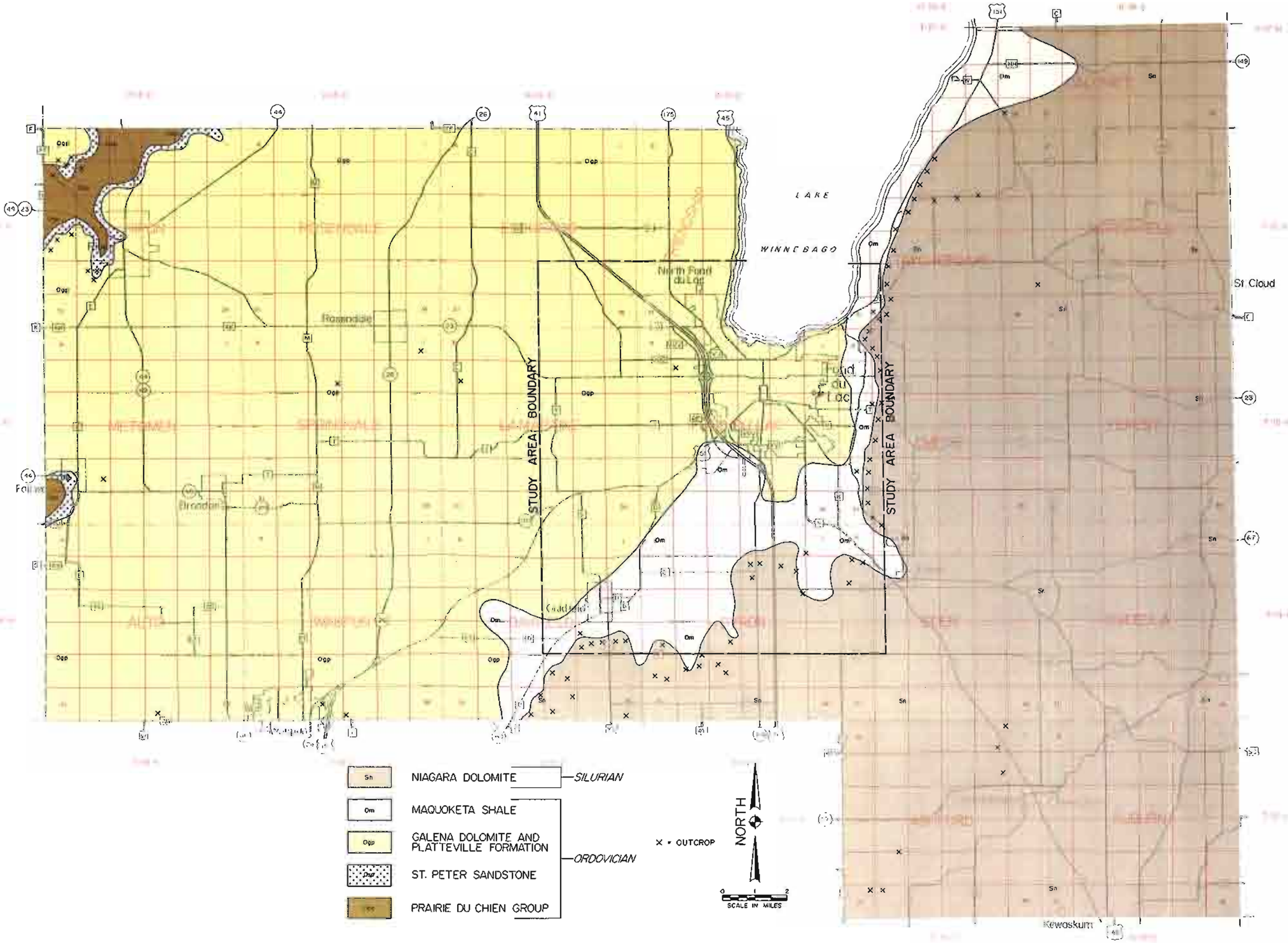
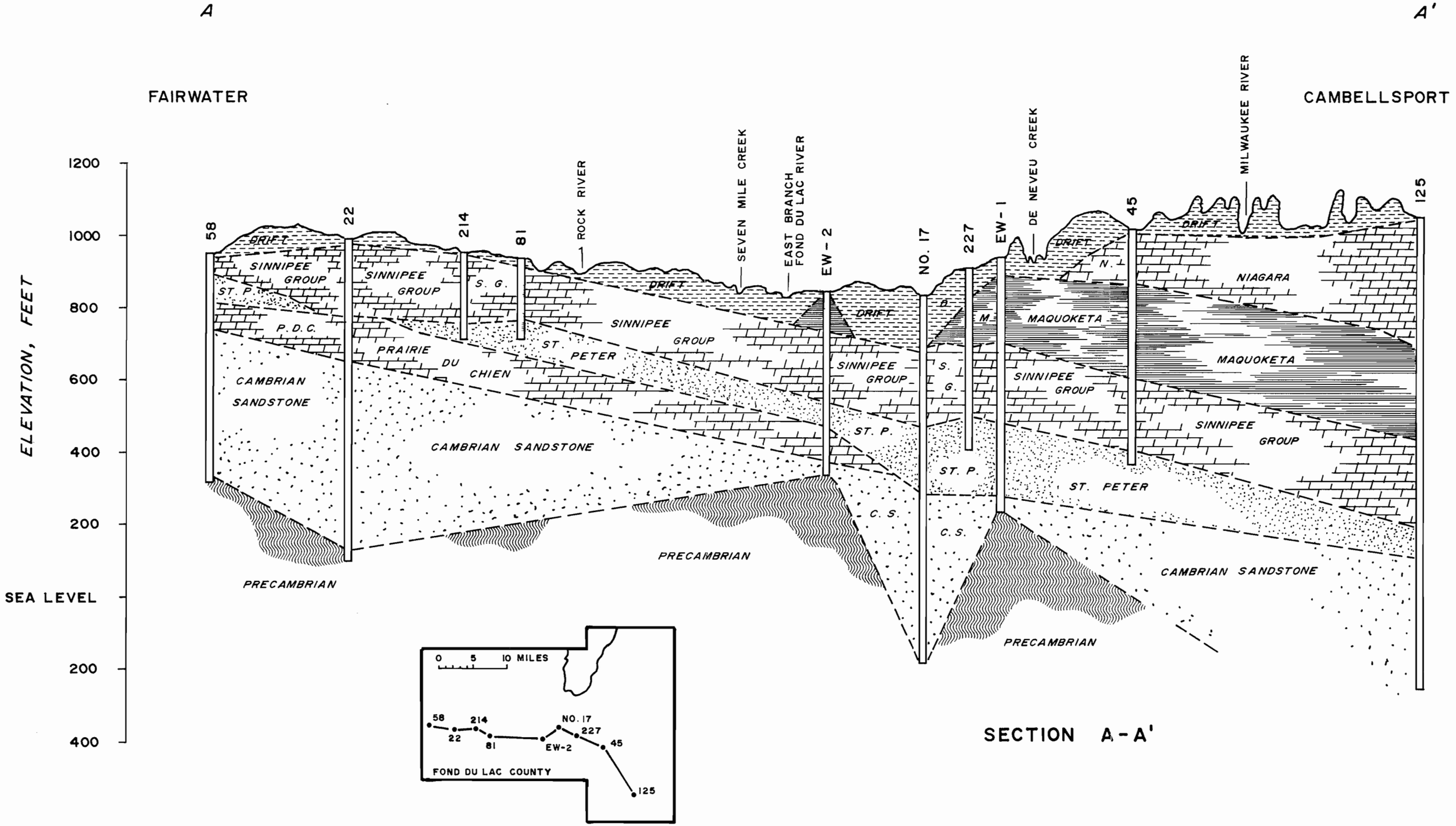


Fig. 3-4 Bedrock Geology

Table 3-1 Lithology and Water Yielding Properties of Rock Units in the Fond du Lac Area

Geologic age (system)	Rock unit name(a)			Lithology/thickness in feet(b)	Water yielding characteristics
	Group	Formation	Member		
		(alluvium)		Clay,peat, silt, sand and gravel/0 to 10	Not an important source of groundwater
Quaternary		(glacial drift)		Unstratified till and stratified clay, sand, and gravel/0 to 150	Can yield large amounts of water from stratified sand and gravel. Important only east of the Niagara Escarpment.
Silurian		(Niagaran Series: informally called the Niagara formation or the Niagara dolomite)		Dolomite, medium gray to white. Generally massive with some coral reefs. Fractures are abundant but are variably distributed/0 to 300	Important aquifer in areas east of the Niagara Escarpment. Yields water from fractures and solution openings along bedding planes.
?		Neda		Shale, with some dolomite/0 to 15	Not an important source of groundwater.
Ordovician		Maquoketa		Shale, medium-bluish gray, dolomitic, interstratified with thin beds of light gray and medium gray dolomite/0 to 210	Not an important source of groundwater. Tends to slough in wells and is generally cased off.
	Sinnipee	Galena Decorah Platteville		Massive, light gray to gray dolomite. Secondary porosity along fractures and bedding planes/155 to 335	Yields small to moderate amounts of water, primarily in areas where it is not overlain by the Maquoketa Shale.
	St. Peter	Glenwood	Tonti Reedstown	Fine to medium grained sandstones, dolomitic in some places. Shale occurs in the Reedstown/40 to 160	Yields small to large amounts of water. Important as an aquifer near Fond du Lac, especially in the south well field.
	Prairie du Chien			Dolomite, cherty, thin bedded to massive. Some layers of sandstone and shale. Not divided into formations in the Fond du Lac area/0 to 115	Yields small quantities of groundwater to wells. Acts as a confining bed where it overlies Cambrian sandstones.
Cambrian	Tunnel City Elk City	(Trempealaun Stage: informally called the Trempealau formation)		Very fine to coarse-grained sandstone, dolomitic, silty, with some layers of shale, siltstone, and dolomite; large facies changes in short distances in Fond du Lac area/0 to 440	Important aquifer. Yields small to large quantities of groundwater depending on permeability and thickness.
Precambrian		(crystalline rocks)		Quartzite, granite, schist, and gneiss/ unknown thickness	Not an aquifer where overlain by younger rock units.

(a) Rock units are classified by members, formations, and groups. Several members comprise a formation. Two or more formations comprise a group. Rocks are also classified by age units (as compared to physical units). In increasing periods of time, the units are; stage, series, and system. Only system names are used here, except where a series or stage name is the only official one shown on the most recent Stratigraphic Nomenclature Chart, published by the WI Geological & History Survey. Rock units are not identified by rock unit name and unofficial rock unit names are in parentheses.
(b) Thickness of the unit is based on well logs within 15 miles of Fond du Lac.
(c) A dashed line between rock units indicates that an unconformity exists between these units. An unconformity represents an erosion surface on the top of the lower unit. Solid lines between units indicate that deposition, with no intermediate erosion period, was continuous.



SECTION A-A'

INDEX MAP SHOWING LOCATION OF WELLS IN SECTION A - A'

Fig. 3-5a Geologic Cross Section

B

WAUPUN

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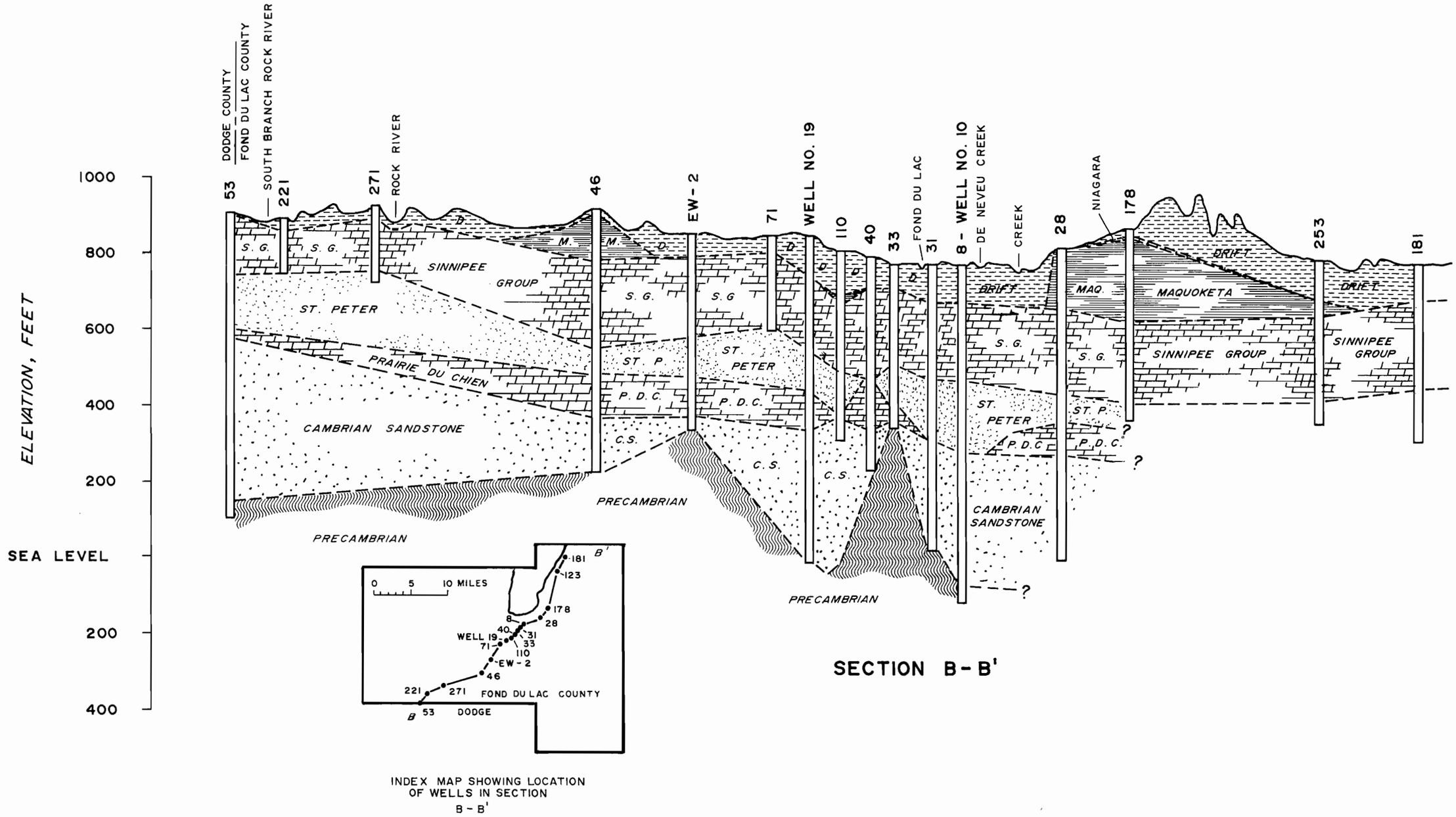
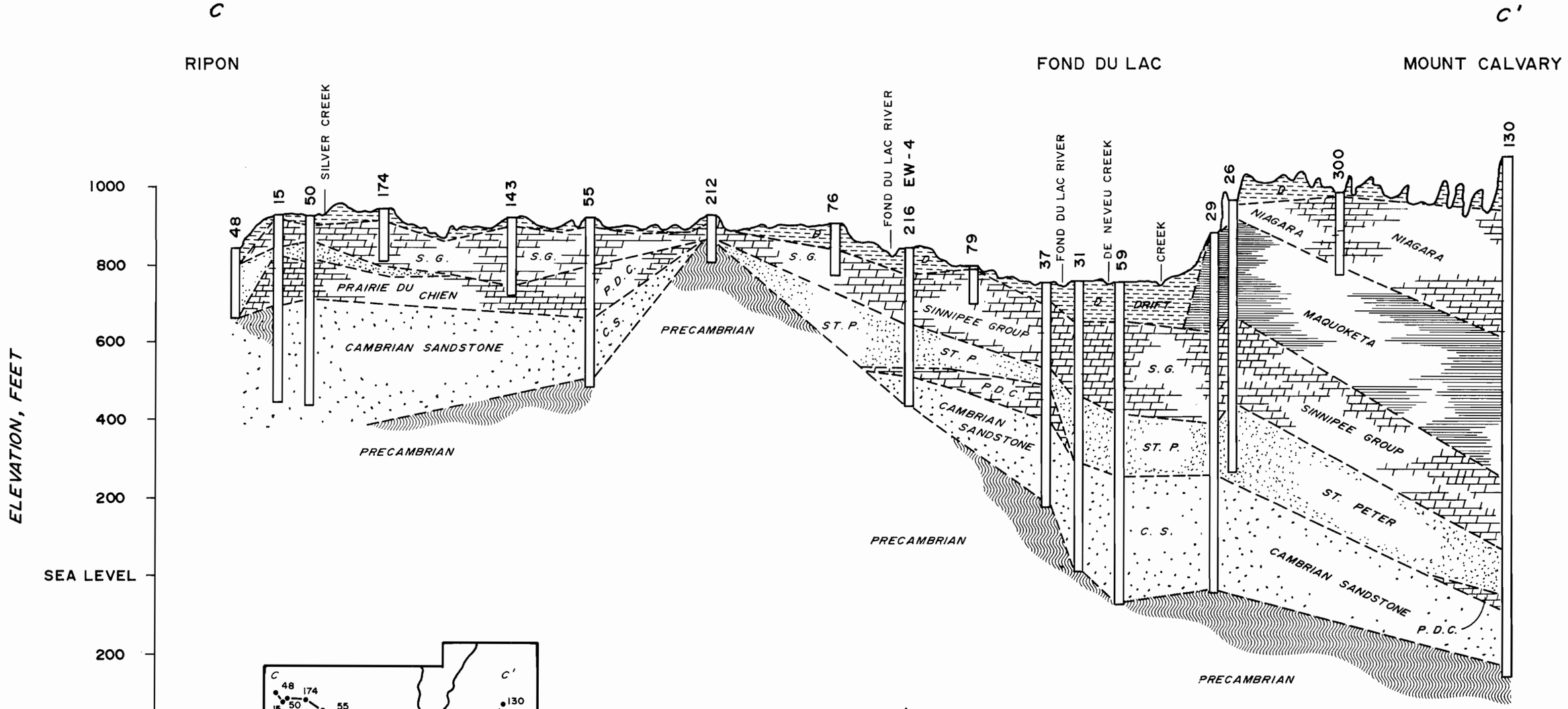


INDEX MAP SHOWING LOCATION OF WELLS IN SECTION B - B'

SECTION B - B'

Fig. 3-5b Geologic Cross Section



INDEX MAP SHOWING LOCATION OF WELLS IN SECTION C - C'

SECTION C - C'

Fig. 3-5c Geologic Cross Section

The St. Peter Group, which is informally known as the St. Peter sandstone, is one of the major water-producing units in the Fond du Lac area. The unit is primarily a fine to medium-grained consolidated sandstone that is dolomitic in some places. The upper formation, the Glenwood, is not as prolific a water producer as the middle Tonti member. The lowest member, the Reedstown, also produces moderate amounts of groundwater, but tends to be shalely and less permeable. The thickness of the St. Peter Group in the City of Fond du Lac area well logs ranges from about 40 to 160 feet.

The St. Peter Group was deposited on the eroded surface of the Prairie du Chien Group. The contact between the groups has an irregular surface, indicating erosion of the Prairie du Chien and older rocks prior to deposition of the St. Peter. The St. Peter sandstone is thick where the Prairie du Chien is thin or missing. Older Cambrian rock units may also be missing and the St. Peter may be in direct contact with the Precambrian basement complex in the areas west of Fond du Lac as shown in Figure 3-5c.

The Prairie du Chien Group consists of cherty dolomite with thin, interbedded layers of shale. These rocks have low permeabilities, but yield small amounts of water to wells from openings along fractures and bedding planes. Thickness of the Prairie du Chien Group near Fond du Lac ranges from 0 to more than 200 feet.

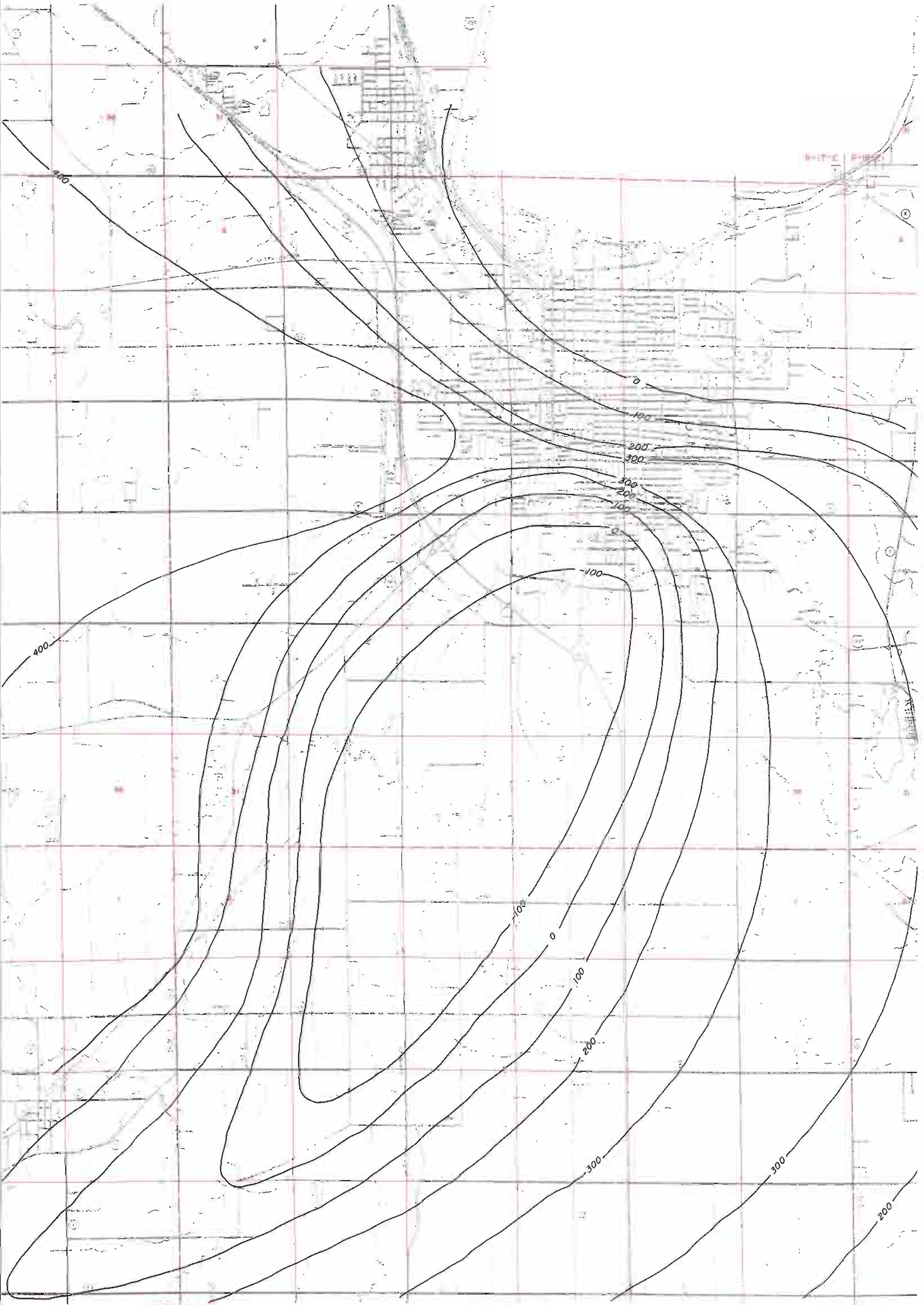
The contact of the Prairie du Chien Group and the underlying Cambrian rock units also represents a period of erosion. Rock unit correlations between wells have not been made in this report because well logs compiled at differing times have described the rock units by system (Cambrian undifferentiated), by group (Trempoeleauan, Tunnel City, and Elk Mound), and even by formation and member (Galesville, Eau Claire).

All of the Cambrian rock units are very fine to coarse-grained sandstones, with dolomitic and silty layers. Layers of shale, siltstone, and dolomite are also interbedded. The units change lithology (facies changes) in short distances, making correlations even more difficult than normal. The units that comprise the Tunnel City and the Elk Mound groups have been assumed to be the major sources of groundwater in the Fond du Lac area.(1) Permeabilities of these rock units, however, are variable, and at any given well may produce only limited amounts of groundwater.

Crystalline Basement Rocks. Crystalline rocks of Precambrian age form the basement rocks in Fond du Lac County. The crystalline rocks are primarily quartzite, but include granite, schist, and gneiss. The crystalline rocks yield only small amounts of water to wells. Where basement rocks are overlain by more permeable rock units, as in Fond du Lac County, contact between the two units constitutes the deepest practical drilling depth for a water supply well.

The surface of the crystalline basement rocks has a slope of 20 to 30 feet per mile towards the southeast on a regional scale. Near Fond du Lac, however, this surface exhibits large amounts of relief, as shown on Figure 3-6. As additional water wells are drilled to bedrock, the shape of the buried crystalline topography will be better defined.

Geologic Structure. The topography of the basement rock surface in Figure 3-6 shows a deep basin beneath the City of Fond du Lac's south well field, and a narrow ridge between the north and south well fields that becomes a wide



LEGEND

—100— PRECAMBRIAN SURFACE CONTOURS

Fig. 3-6
Precambrian Rock Surface Contours

elongated ridge to the west of the city. The map is based on production and exploratory well logs. One such exploratory well, an observation well about 30 feet from Well No. 17, indicates that the contact of the Cambrian sandstones and the basement is more than 100 feet higher in the test hole than it is in the production well. Construction records from production wells in the vicinity of the exploratory well indicate the presence of large boulders of crystalline bedrock. It appears that some wells may have been terminated at a boulder rather than the contact between the Cambrian sandstones and the crystalline bedrock. This may explain the variations in the depth to the basement rock.

Groundwater Quality. Groundwater throughout the region is generally of good quality. With the exception of radium, water quality problems are primarily aesthetic and are generally due to high concentrations of iron, dissolved solids, and hardness. Chemical characteristics of well water in the Fond du Lac area are summarized in Table 3-2. The dissolved solids, chloride, and sulfate concentrations increase and saline water is a problem toward the northern end of Lake Winnebago.(6)

Table 3-2 Chemical Characteristics of Well Water in the Fond du Lac Area(6)(7)

Characteristic	Concentrations, mg/l					
	Winnebago State Hospital(a)	Brandon Well No. 1(b)	Campbellsport Well No. 1 (b)	Mt. Calvary Well No. 1 (b)	North Fond du Lac Well No. 2 (b)	Oakfield Well No. 1 (b)
Alkalinity	224	288	238	284	245	244
Calcium	229	67	118	109	74	59
Chloride	64	4	23	40	39	21
Fluoride	0.9	0.3	0.8	0.2	0.5	0.7
Hardness	667	312	410	444	318	288
Iron	1.1	1.4	0.62	1.14	0.38	0.12
Magnesium	23	35	28	42	31	34
Manganese	0.08	0.04	0.04	0.05	0.04	0.04
Nitrate-Nitrite	0.1	0.5	0.5	0.5	0.5	0.5
Sodium	39	4	18	43	16	60
Sulfate	439	24	160	183	58	138
Total Dissolved Solids	940	324	578	664	476	510

(a)Reference (6)
(b)Reference (7)

Radium, a naturally occurring contaminant, has been detected in a large number of water supplies in the Fond du Lac area. The majority of communities in the Fond du Lac area do not have radium levels in violation of the standard although a significant number of communities, including Fond du Lac and North Fond du Lac, are in violation. Some communities, such as Waupun and Beaver Dam, already provide treatment; while other communities, such as Lomira and Mayville, achieve compliance through blending sources of supply.

Soils

Soil characteristics affect the design, construction, and operation of water supply facilities. The proximity of bedrock and groundwater have a direct bearing on the cost of such facilities and the permeability has an influence on recharge of groundwater aquifers and the hydrologic characteristics of streams and rivers.

The principal soils in the study area are the Manawa silt loam, Poygan silty clay loam, and Kewaunee silt loam. Land along the drainage courses in the study area is predominantly DePere silty clay loam or Poygan Silty clay loam. There are three other major soils series scattered throughout the study area. The characteristics of these soils series are summarized in Table 3-3.

Table 3-3 Soil Characteristics

Symbol	Soil Name	Depth to Seasonal Groundwater, feet	Depth to Bedrock, feet	Shrink-Swell Potential	Risk of Corrosion		Permeability, in/hr	
					Uncoated Steel	Concrete	Topsoil	Subsoil
Kn,Ko	Kewaunee	>5.0	>5.0	High	Moderate	Low	0.2-2.0	0.06-0.2
Ma,Mc	Manawa	1 - 3	>5.0	High	High	Low	0.6-2.0	0.06-0.2
Py	Poygan	0 - 1	>5.0	High	High	Low	0.6-2.0	0.06-0.2
Km	Keowns	0 - 1	>5.0	Low	High	Low	0.6-2.0	0.2 -0.6
De	De Pere	0 - 1	>5.0	High	Moderate	Low	0.6-2.0	0.2 -0.6
Pf	Peebles	3 - 5	>5.0	High	Moderate	Low	0.6-2.0	0.06-0.2
Oh,Ok	Oshkosh	3 - 5	>5.0	High	Moderate	Low	0.6-2.0	0.06-0.2

The Manawa series consists of deep, nearly level, and gently sloping soils. The soil is generally located adjacent to wetlands, shallow drainageways, and small depressions. Manawa soils have high available water capacity and slow soil permeability. This soil is saturated to a depth of one to three feet during the wet weather spring and fall months.

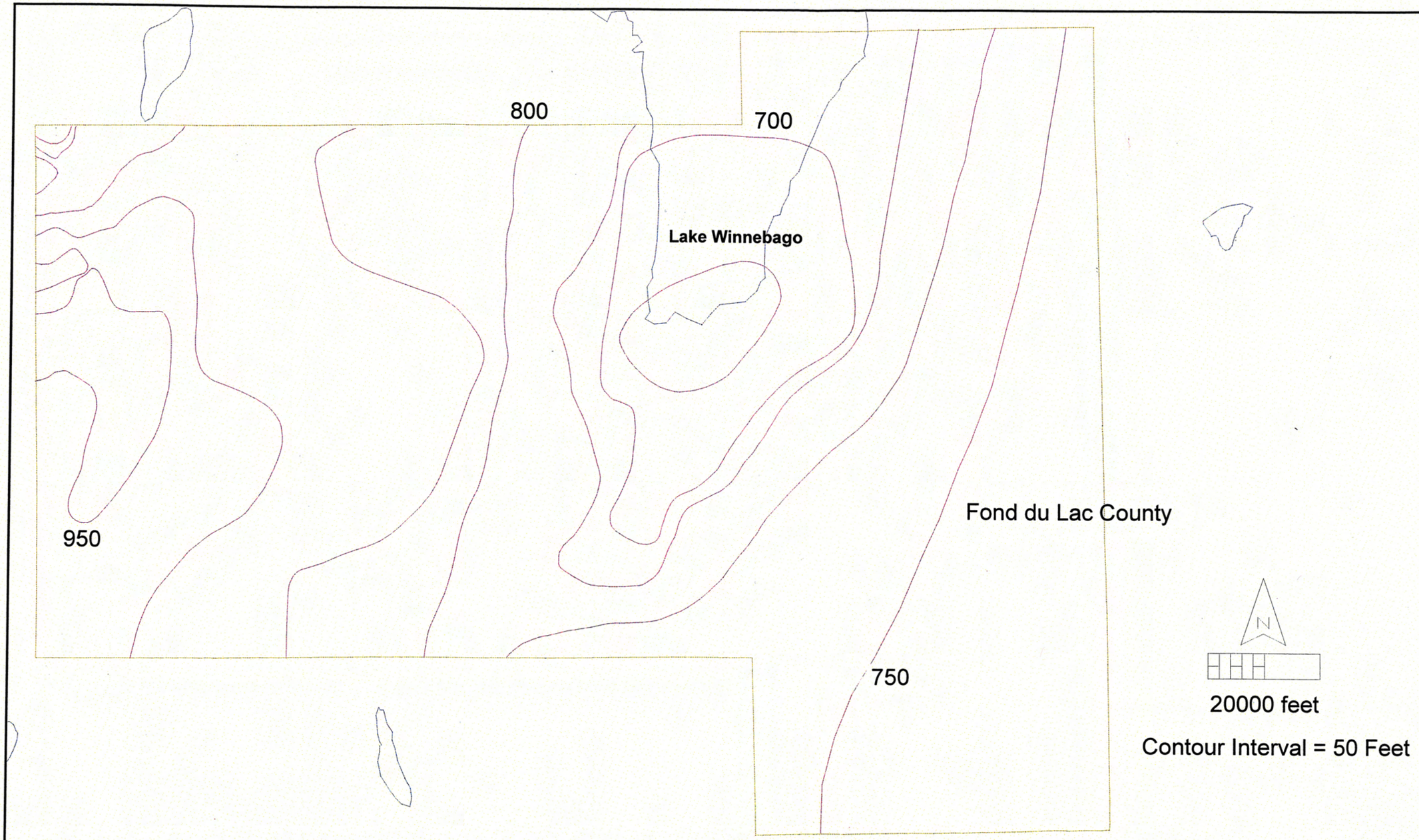
The Poygan silty clay loam soil is the predominant soil series within the city limits. The Poygan series consists of deep, nearly level to gently sloping soils which are poorly drained in upland areas. The topsoil is generally black silty clay loam and the substratum is reddish-brown silty clay. Poygan soils have high available water capacity and have slow permeability. The seasonal high groundwater level is at zero to one foot.

The Kewaunee series consists of deep, nearly level to very steep, well drained soils. The topsoil is very dark gray silt loam and the substratum is reddish-brown clay. This soil series has a very slow permeability and the available water capacity is high. The Kewaunee soils are located primarily adjacent to Lake Winnebago. The seasonal high groundwater level is greater than 5 feet from the surface.

The shrink well potential for the major soil series is high except the Keowns series which is low. Bedrock is located greater than 5 feet from the surface for the major soil series in the study area. The risk of corrosion is moderate to high for uncoated steel and low for concrete. The Alluvial land and DePere silty clay loam located along the drainageways and streams are subject to seasonal flooding.

More detailed information of the soils in the study area can be found in the U.S. Soil Conservation Service soil survey of Fond du Lac County.(8) This information can be used as a guide, but detailed soil investigations are required for design of water supply facilities.

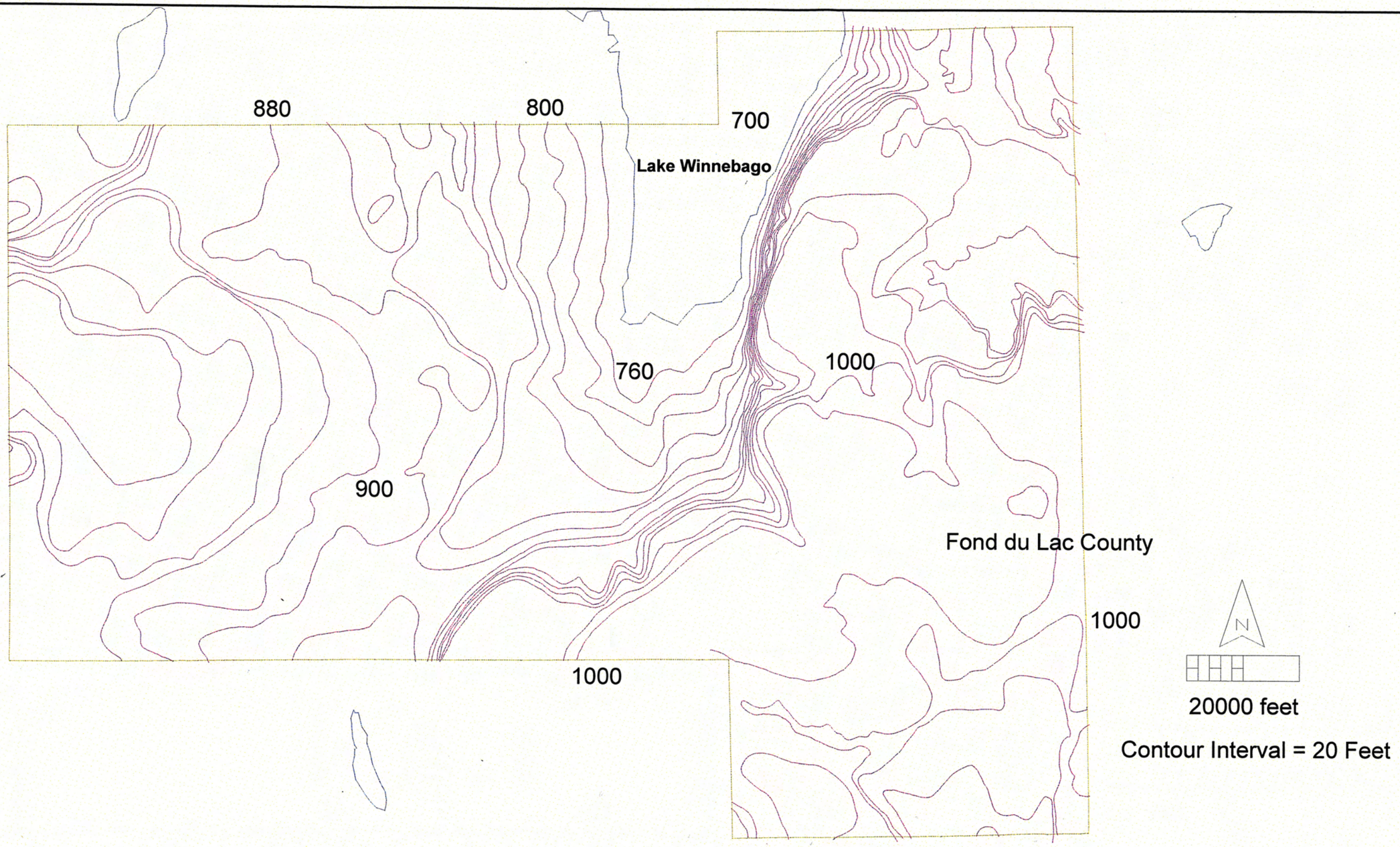
APPENDIX E
POTENTIOMETRIC SURFACE ELEVATION-SANDSTONE BEDROCK AQUIFER



Sanstone Aquifer Potentiometric Surface Elevation, Fond du Lac County

Pfeiffer and Bradbury, 2002

APPENDIX F
WATER TABLE ELEVATION



Water Table Surface Elevation, Fond du Lac County

Pfeiffer and Bradbury, 2002